Statistical Evaluation of the WB-57 Microphysical Data Set during CRYSTAL-FACE

Tim Garrett, Linnea Avallone, Darrel Baumgardner, Hermann Gerber, Bob Herman, Paul Lawson, Tony Strawa

The WB-57 during CRYSTAL-FACE provided an unprecedented variety of microphysical instrumentation for measuring cirrus anvils.

Bulk Measurements

- Ice water content (Harvard, Colorado/JPL)
- Optical extinction at 635 nm (CIN)

Size Distributions and Imaging

- Size distributions (CAPS, VIPS, SPP-100, CPI)
- Imaging (CAPS, VIPS, CPI)

- Size distributions can be integrated to yield bulk properties.

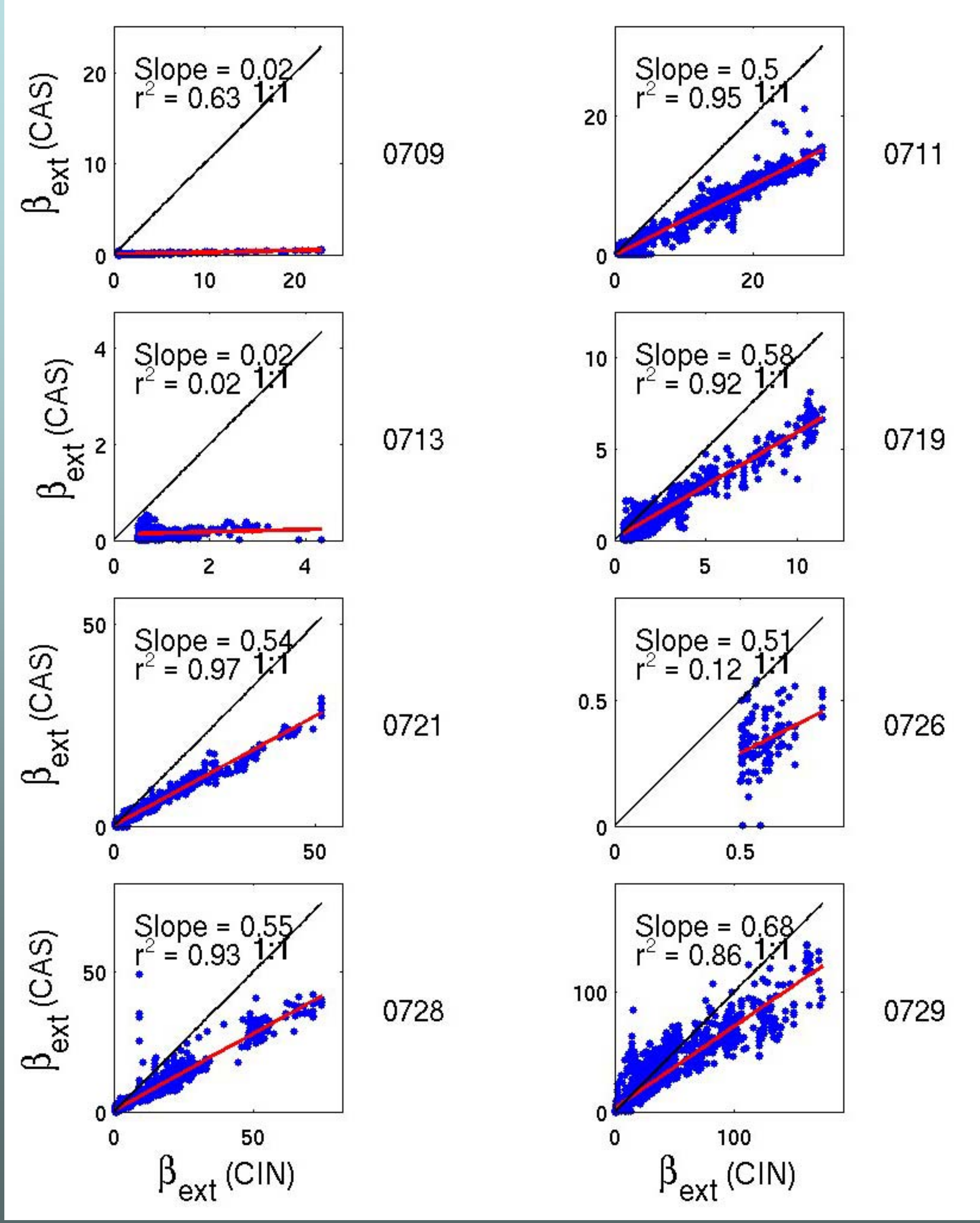
- Are the size distributions and bulk measurements self – consistent?

Extinction

Extinction can also be inferred from the size distribution probe's particle cross-sectional area A_i

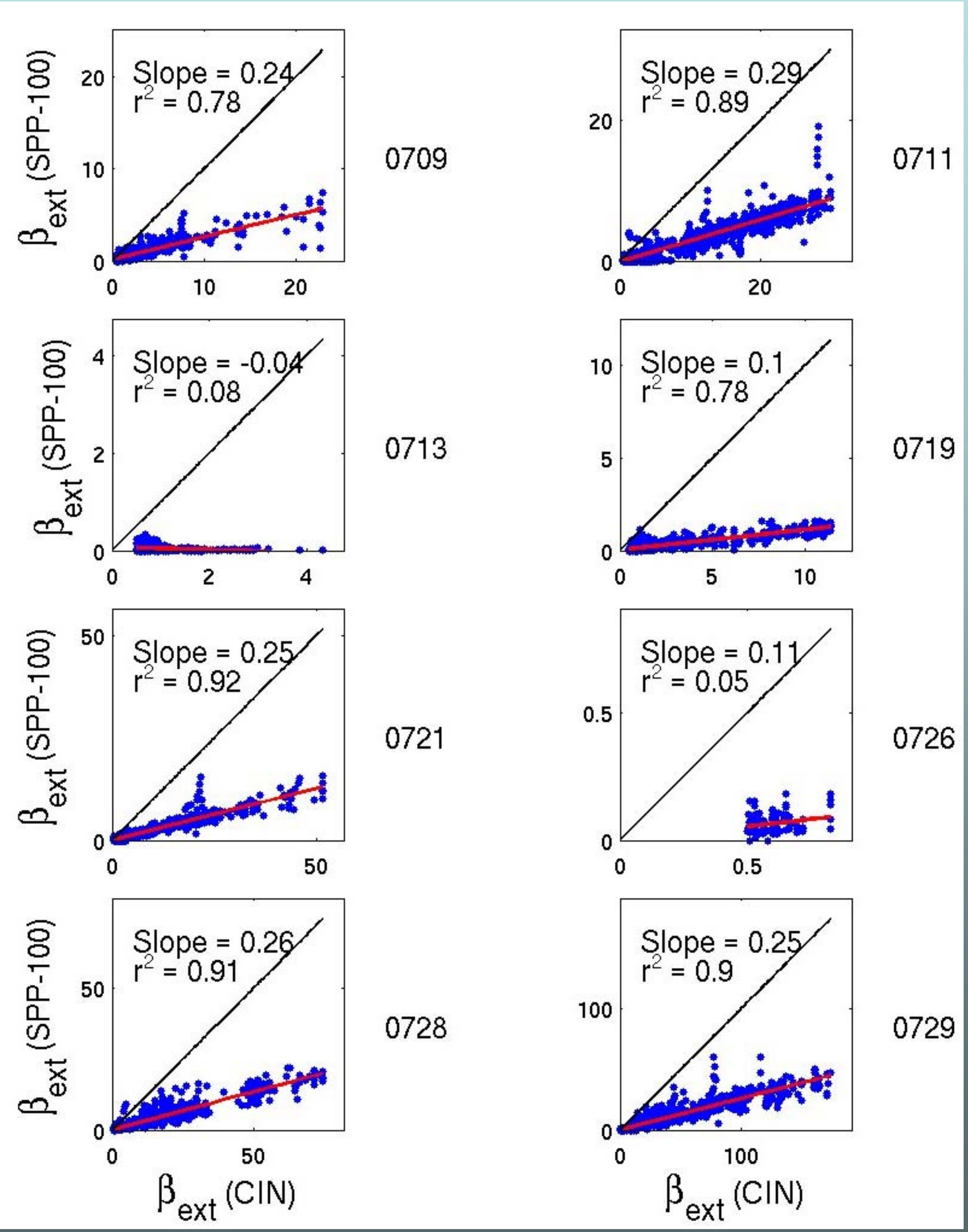
$$\beta_{ext} \cong 2\sum_{i} n_i A_i$$

CAS (CAPS < 42 µm) vs. CIN



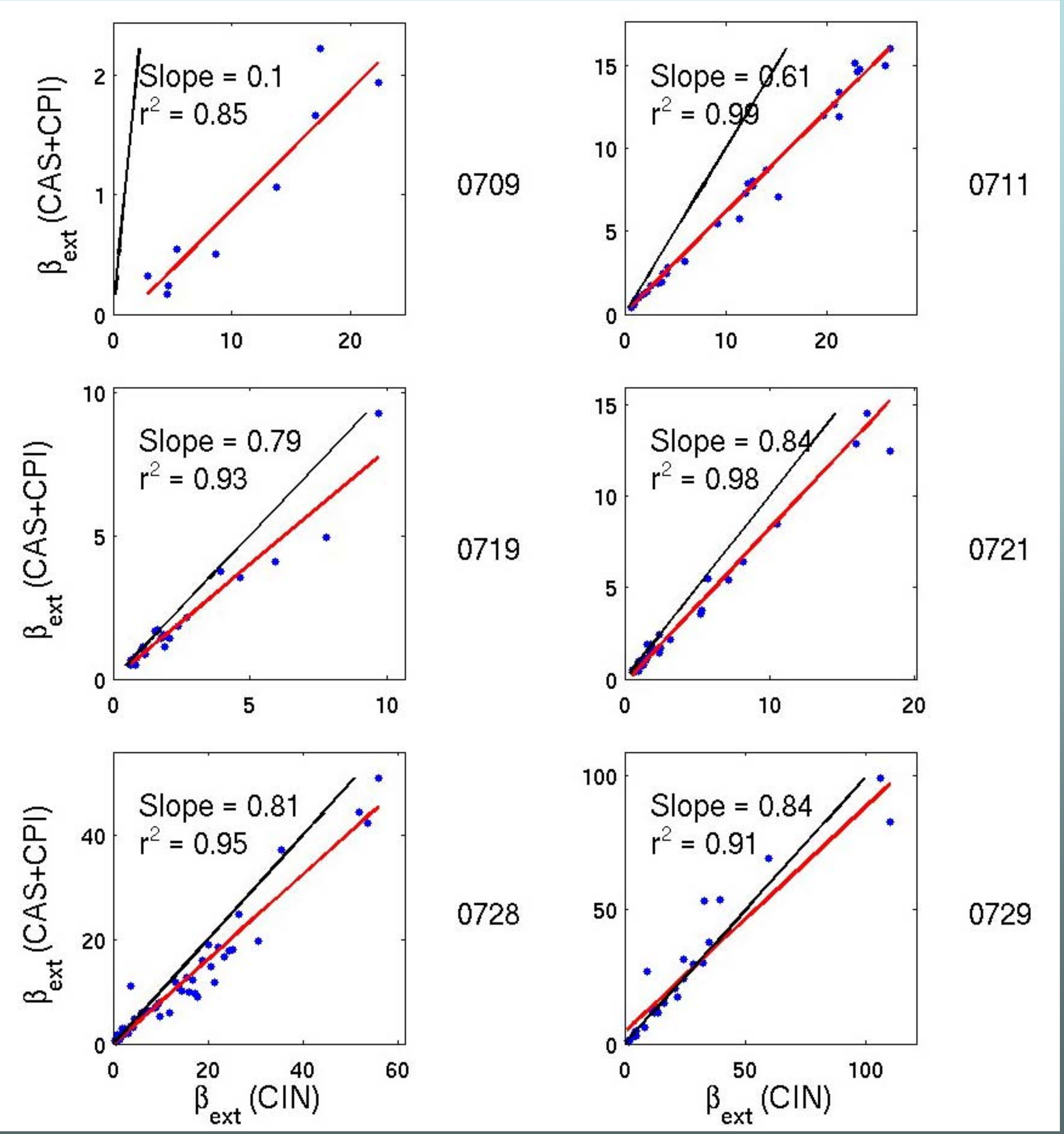
- The measurements are highly correlated.
- CAS extinction is typically about 60% CIN extinction.
- Exceptions are the 13^{th} (a contrail day with very small ice crystals) and the 9^{th}.

SPP-100 (d < 56.2 μm) vs. CIN



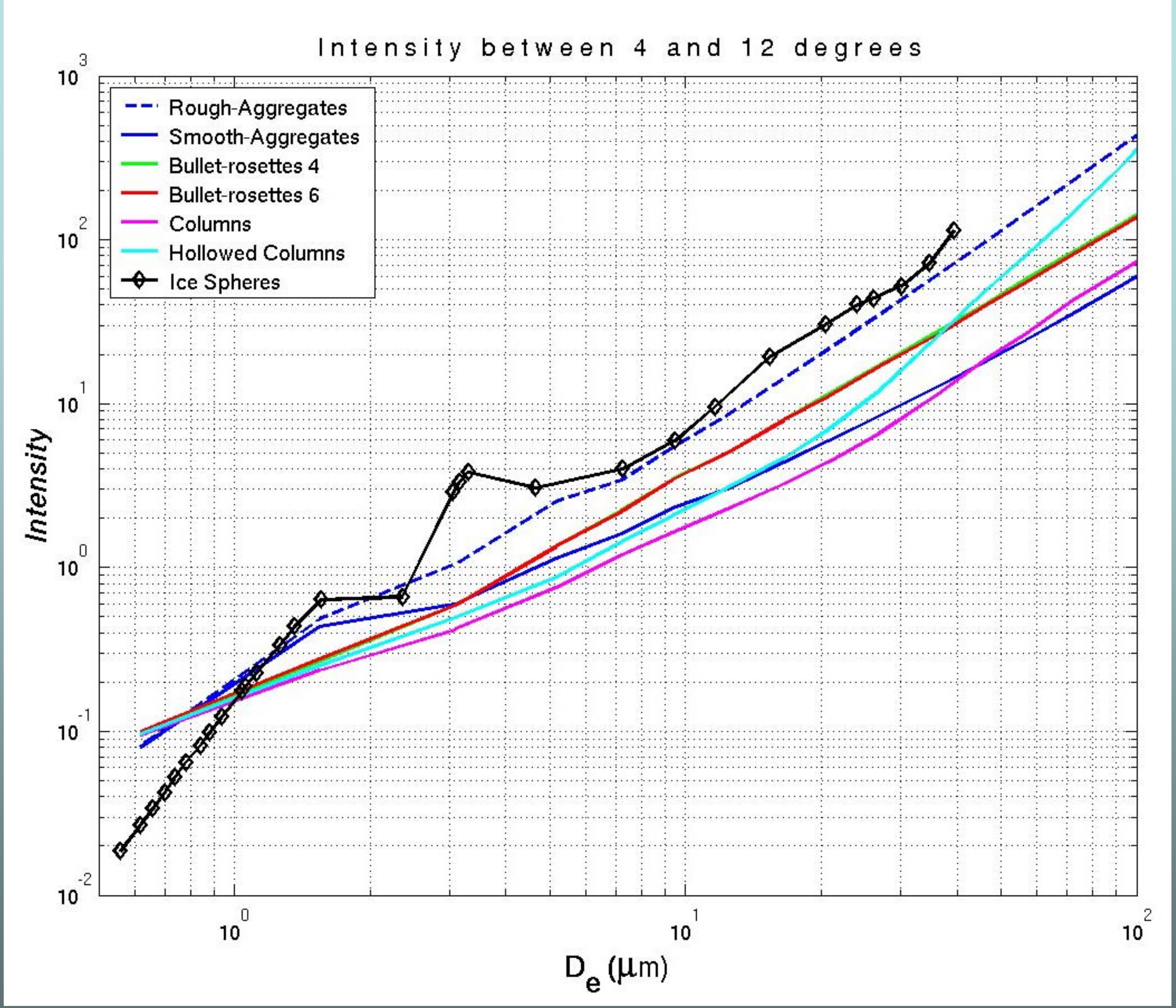
- The measurements are highly correlated.
- SPP-100 extinction is typically about 20% CIN extinction
- The exception is the 13th (a contrail day with very small ice crystals).
- Unlike the CAS the 9th has a slope consistent with other days.

CAS (d < 42 μm) + CPI (d > 55 μm) vs. CIN



- We've added the CPI to the CAS to get the full range of extinction.
- The correlation stays high.
- The agreement with the CIN is pretty good.
- Large crystals are 20% total extinction?

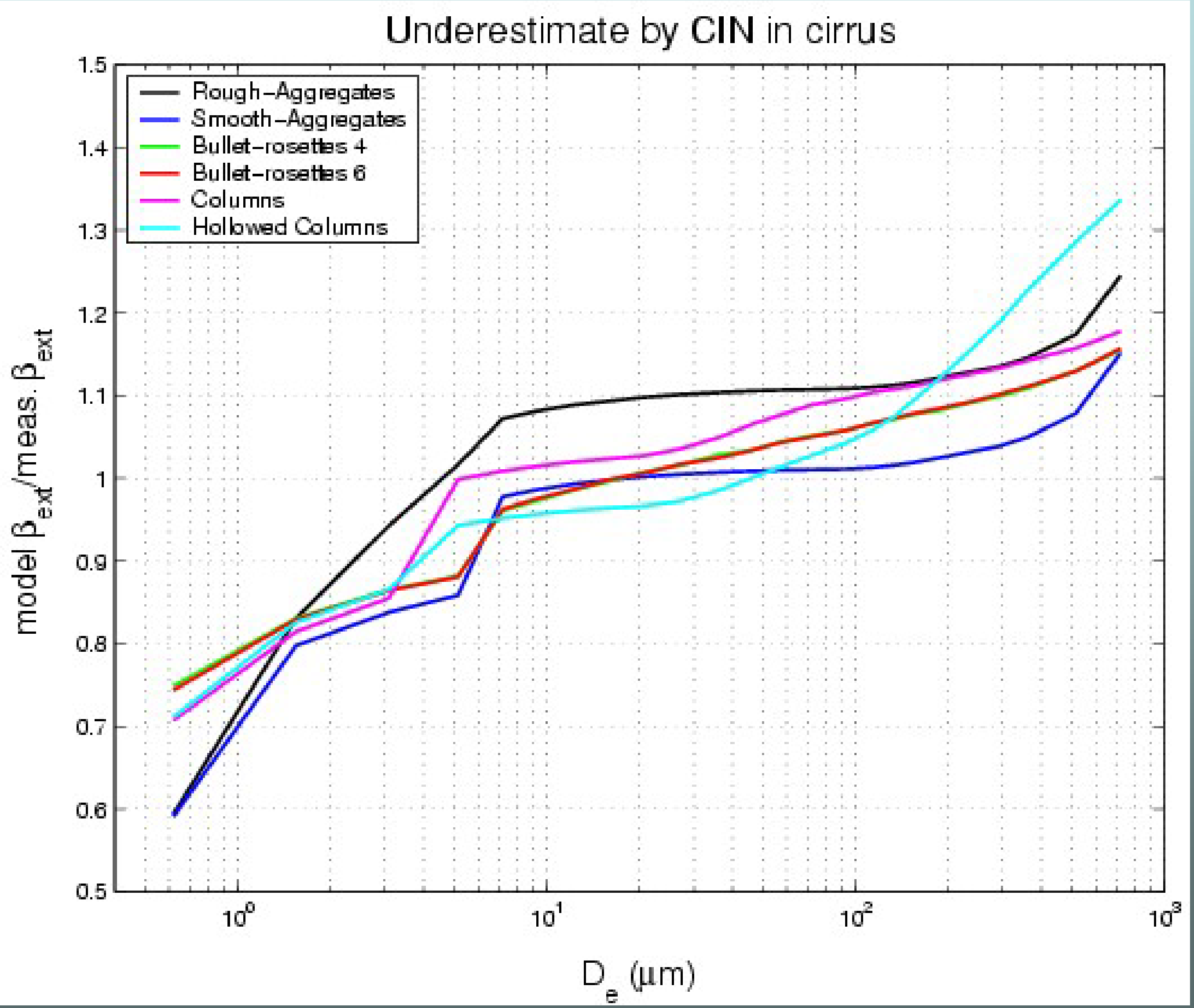
- So generally, the CIN, and the CAS and CPI combined, appear to provide a good characterization of the size and habit distribution of light scattering in cirrus anvils (with exceptions on the 9th and 13th.)
- However there remain some questions.



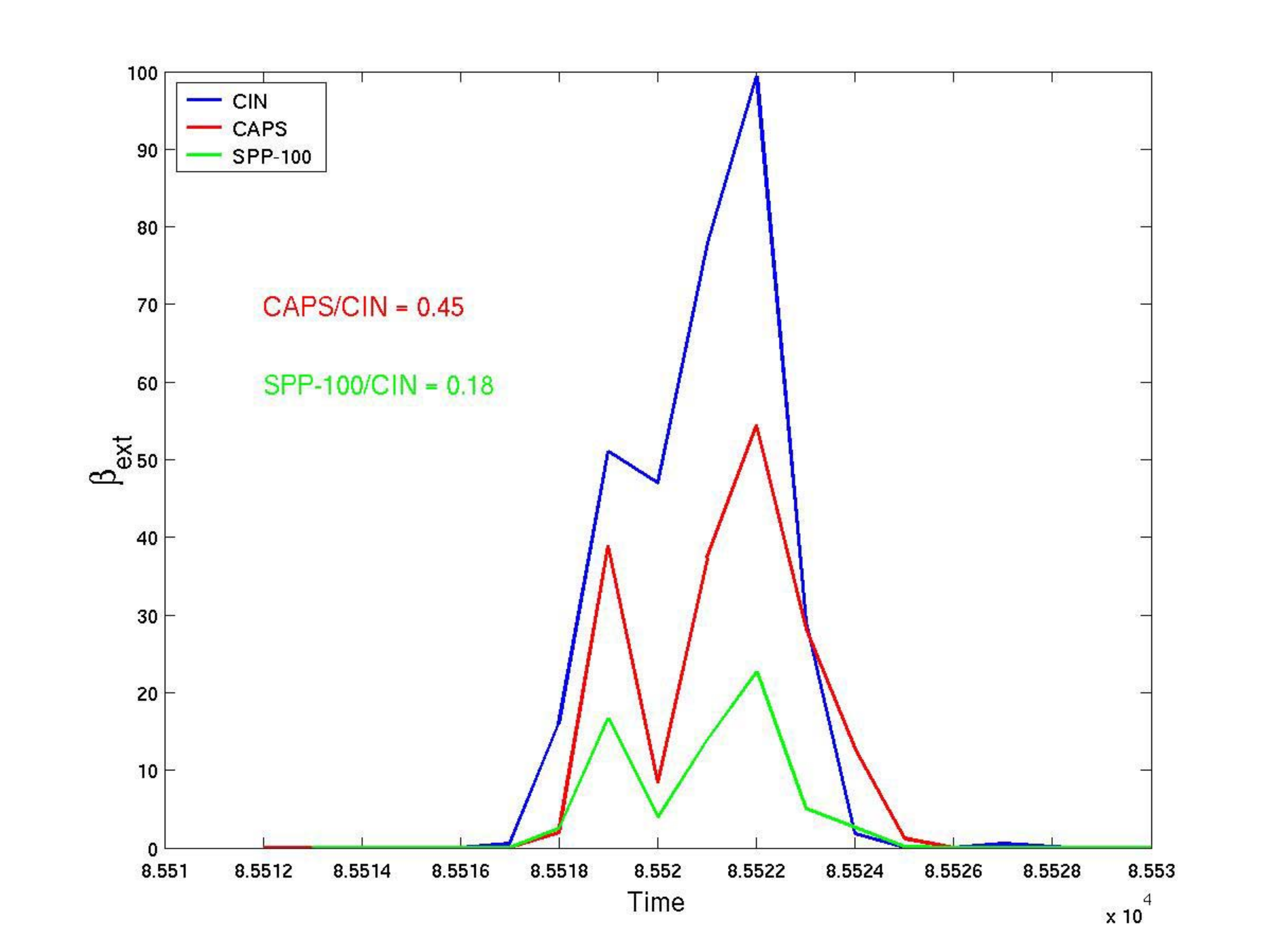
Thanks to Ping Yang for providing ice crystal phase functions

***A priori,* assuming the SPP-100 and CAS probe are measuring ice spheres might lead to errors on the order of 100% in ice crystal sizing.**

Such errors are a second order effect for CIN estimation of extinction (+/- 5%)

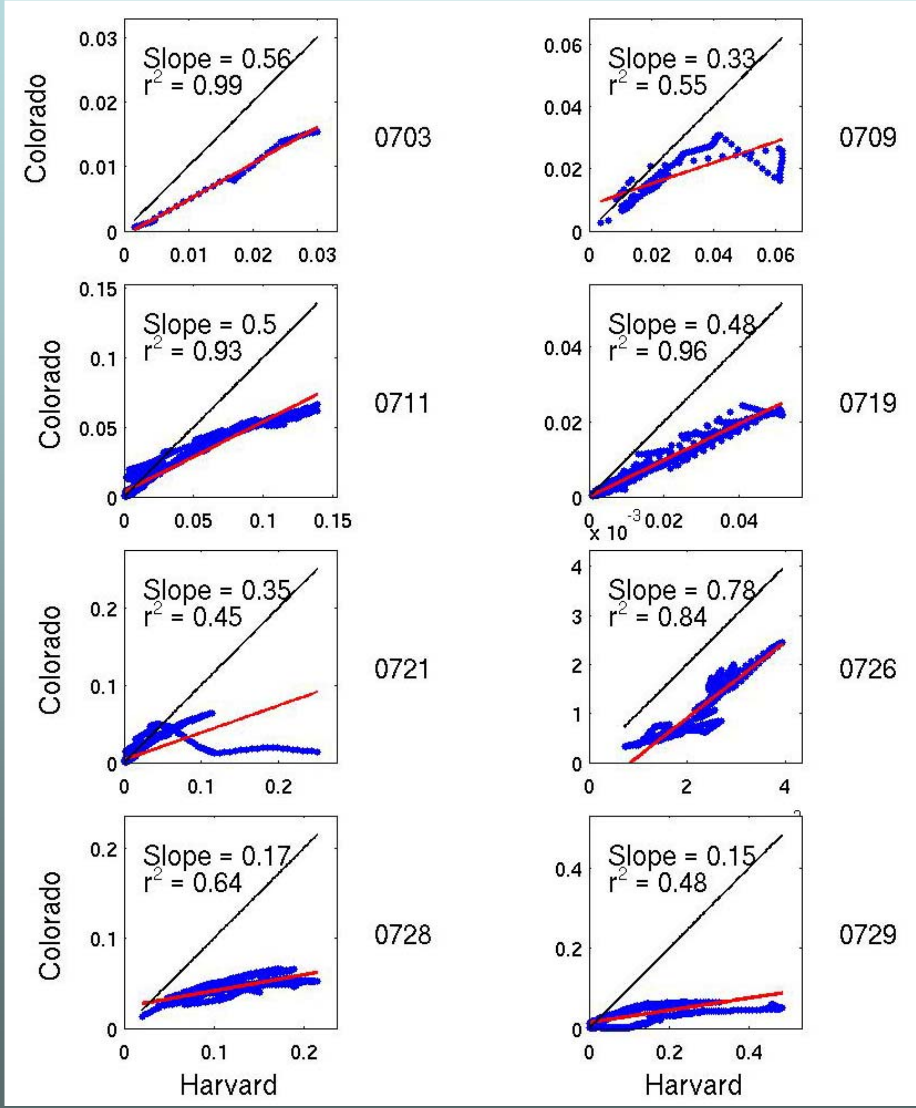


Agreement among probes is poor even in non-precipitating water clouds, and roughly in the same manner as in ice-clouds.



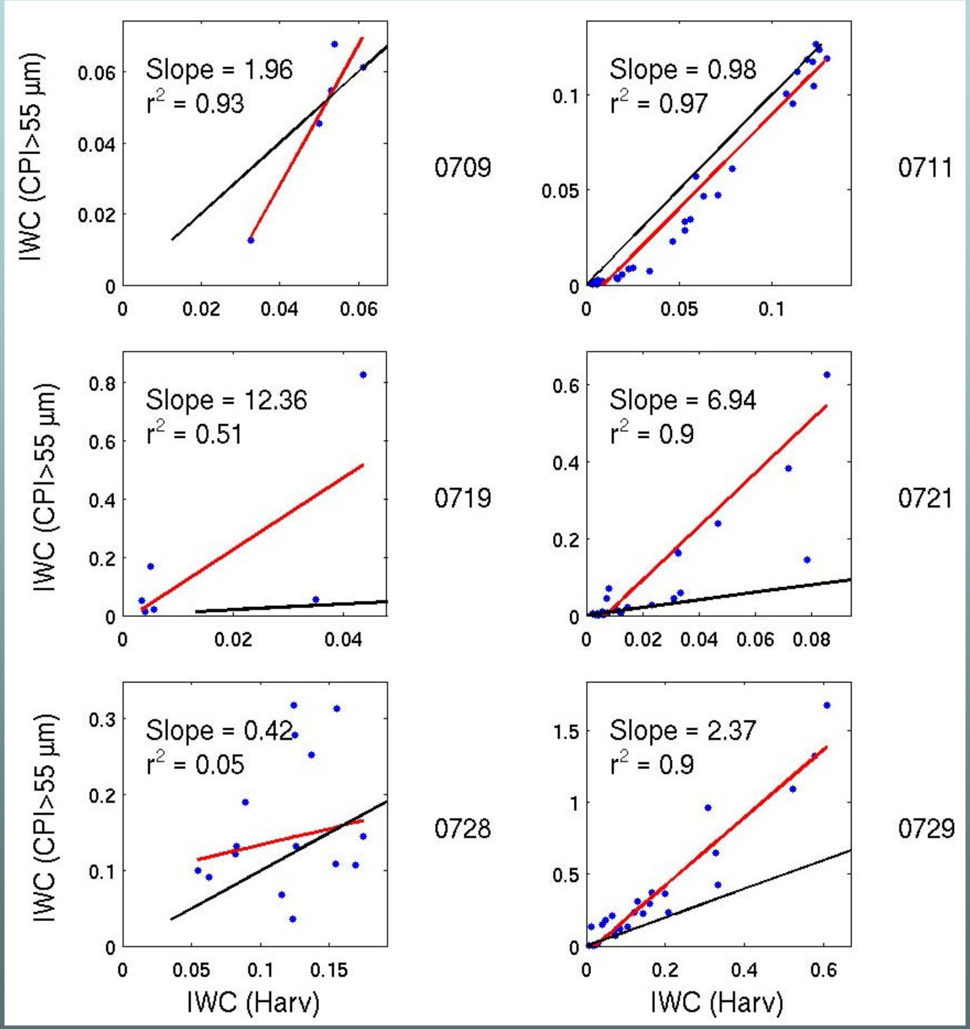
How is the comparison for ice water content?

Colorado vs. Harvard



- The Colorado IWC is a fair bit lower than the Harvard IWC
- The response of the Colorado IWC appears to taper off as IWC gets large.
- The correlation between the two probes is sometimes quite low.

CPI (d > 55 μm) vs. Harvard

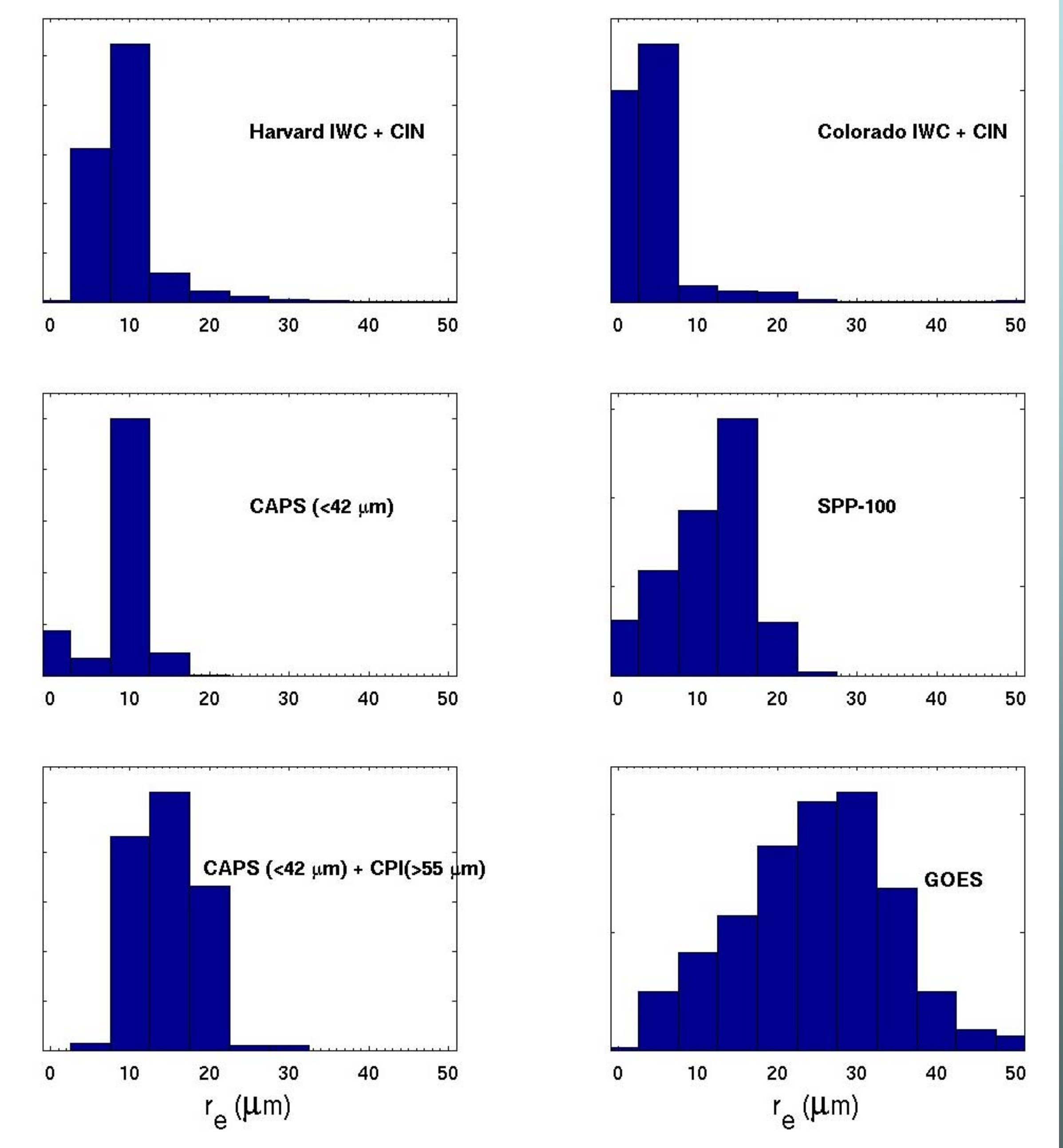


Inferences of IWC from CPI images of large ice crystals bear little relation to Harvard IWC measurements.

Effective radius is the ratio of IWC to extinction. How do different measures of effective radius compare?

$$r_e = 1.64 \times 10^{-3} \frac{IWC}{\beta_{ext}}$$

Effective Radius freq. distribution during CRYSTAL



- GOES is largest
- Colorado/CIN is smallest
- Harvard/CIN, SPP-100 CAS, and CAS/CPI are all in roughly the same ballpark.
- Very small ice crystals dominate anvil radiative properties

Conclusions

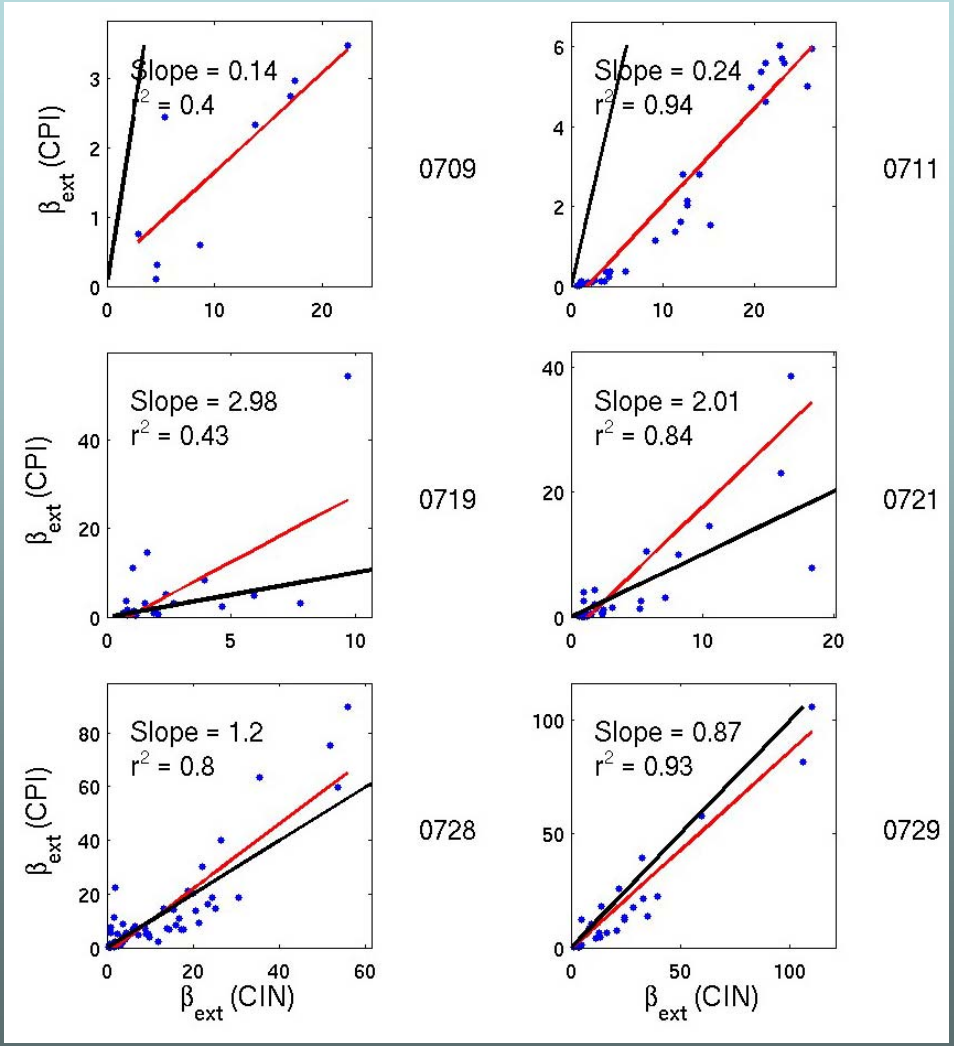
- There remains considerable disagreement among the probes
- The CAS on the 9th is anomalously low compared to all other probes. This was the best day for sub-visible cirrus.
- The Colorado IWC seems too low compared to other instruments.
- The CPI IWC seems strange.

- The CAS, SPP-100, CPI and CIN effectively all measure scattering, so they are well correlated with each other. But they disagree greatly in magnitude. Theoretically, sizing by the CAS and SPP-100 has some problems in ice clouds, but the CIN, CAS and SPP-100 had very poor agreement in a water cloud too.
- The effective radius measured by the WB-57 during CRYSTAL was generally about 10 μm, much smaller than retrieved values from the GOES Satellite.

The truth is out there……..

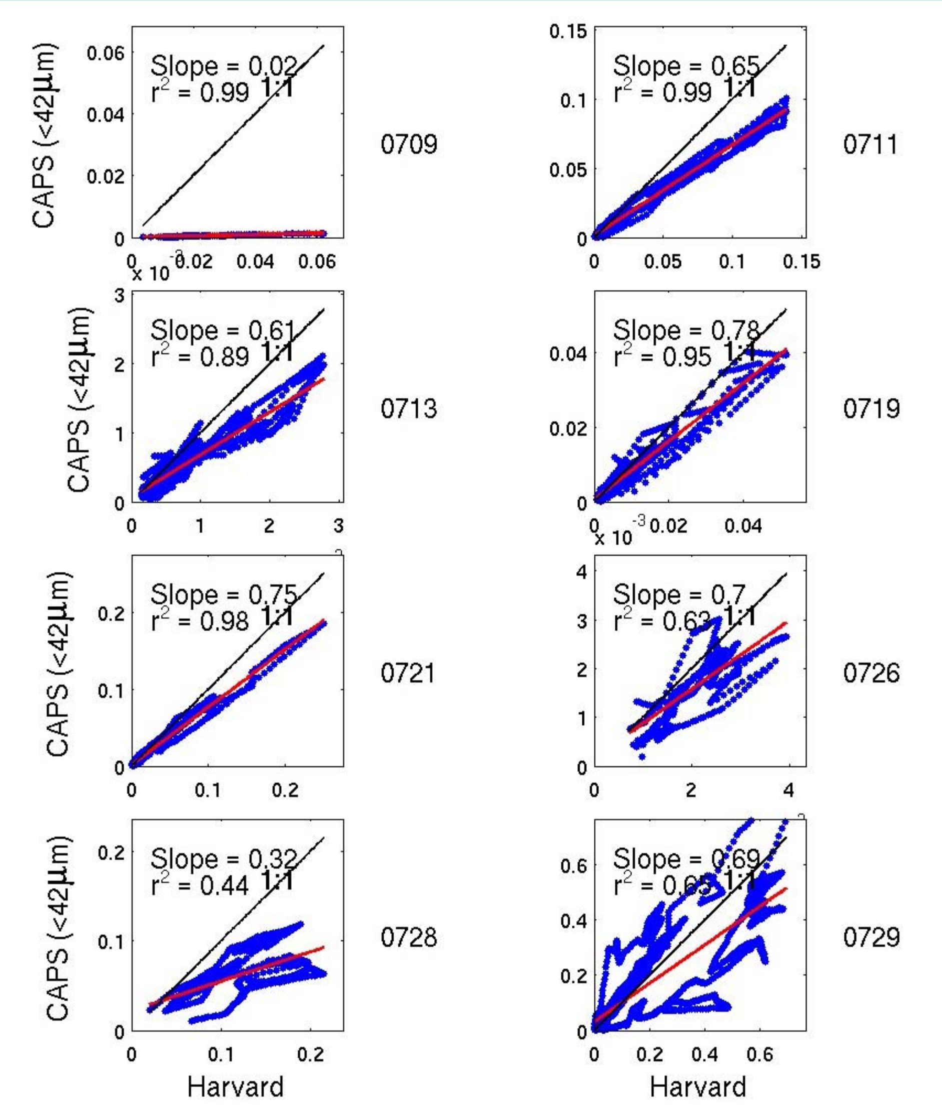
Thanks to everyone who answered questions about their instruments and data

CPI (d > 10 μm) vs. CIN

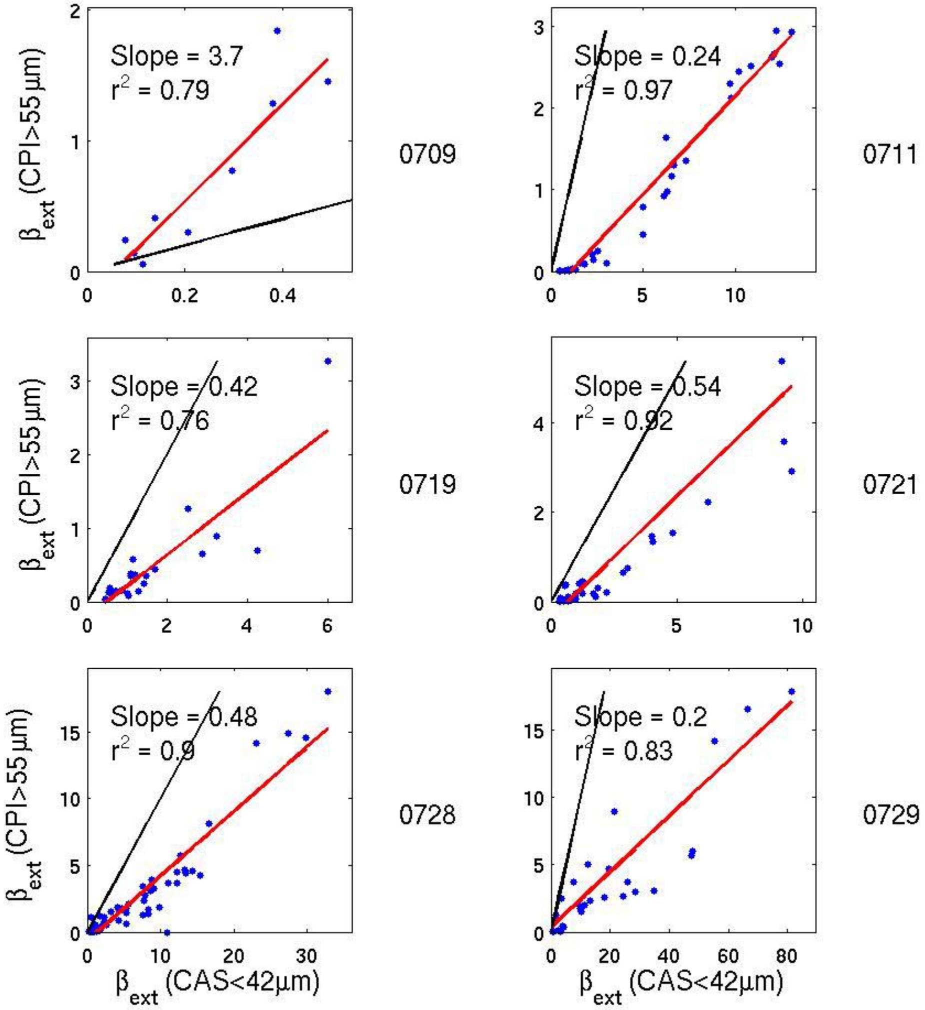


The entire range of the CPI extinction shows inconsistent agreement and correlation with the CIN.

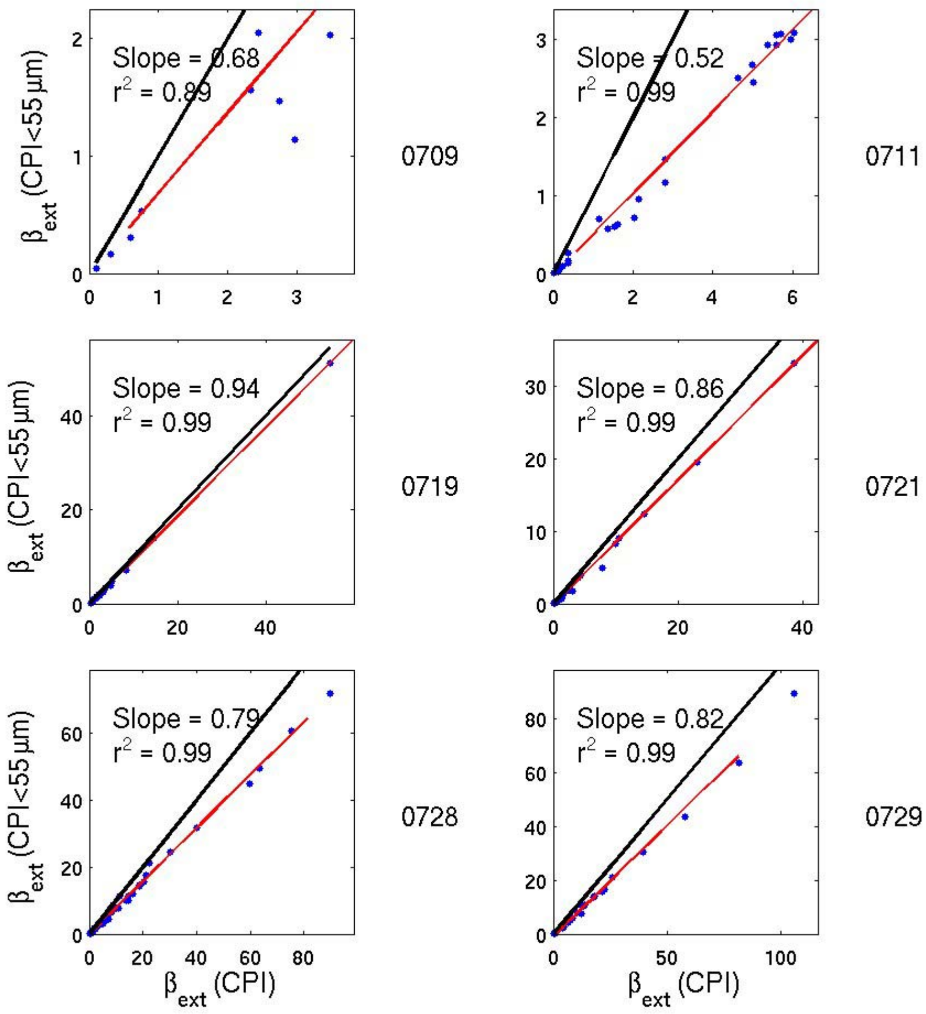
CAS (d < 42 μm) vs. Harvard



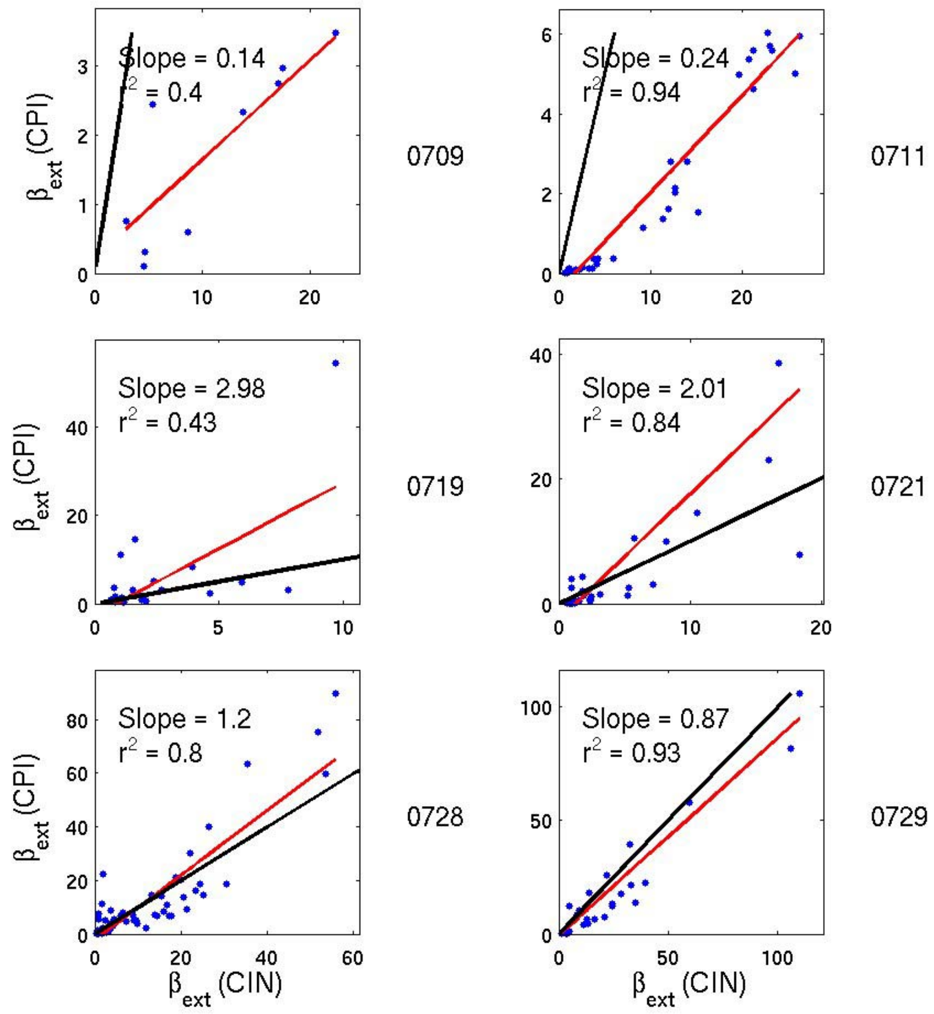
Again the CAS data from the 9th seems anomalously low, but there is, overall, surprisingly good agreement and correlation between the probes. Assumed a bulk ice density for ice.



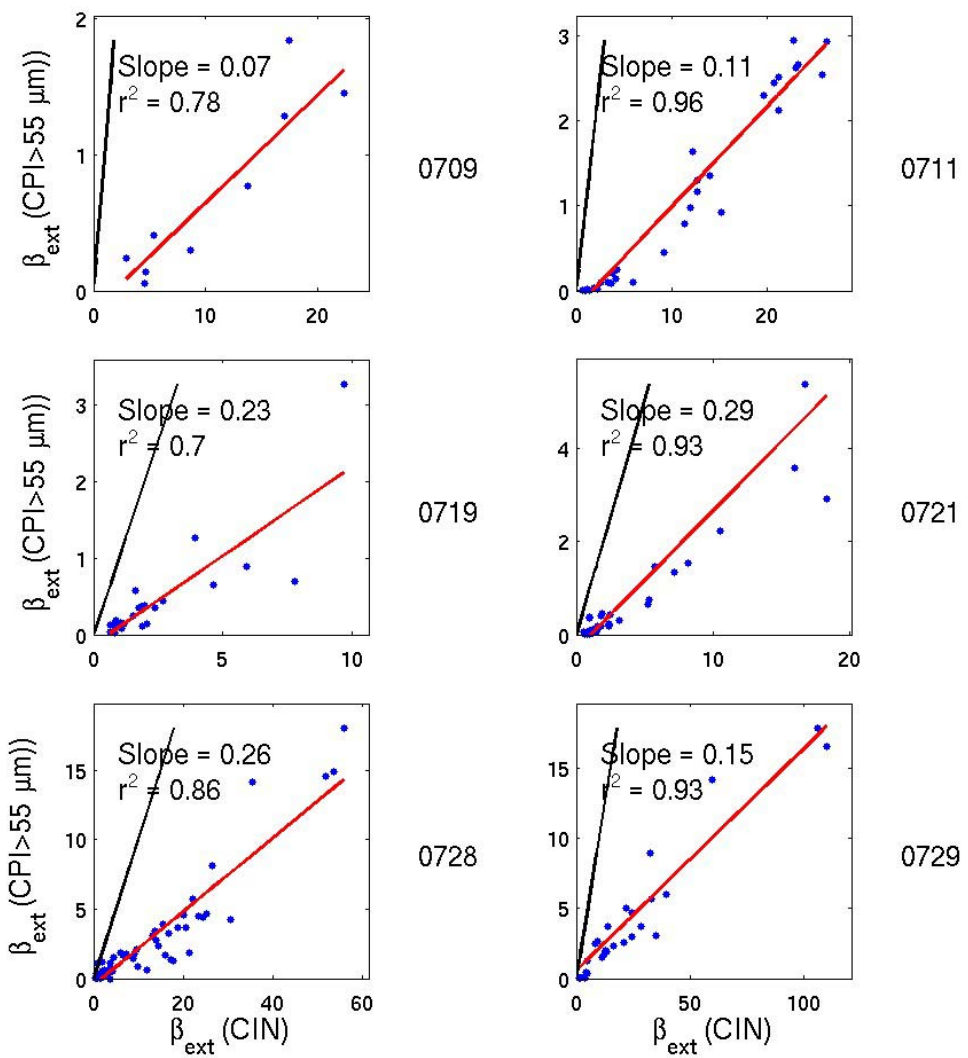
Slope = 3.7
r2 = 0.79
0709
Slope = 0.24
r2 = 0.97
0711
Slope = 0.42
r2 = 0.76
0719
Slope = 0.54
r2 = 0.92
0721
Slope = 0.48
r2 = 0.9
0728
Slope = 0.2
r2 = 0.83
0729
βext (CPI>55μm)
βext (CAS<42μm)



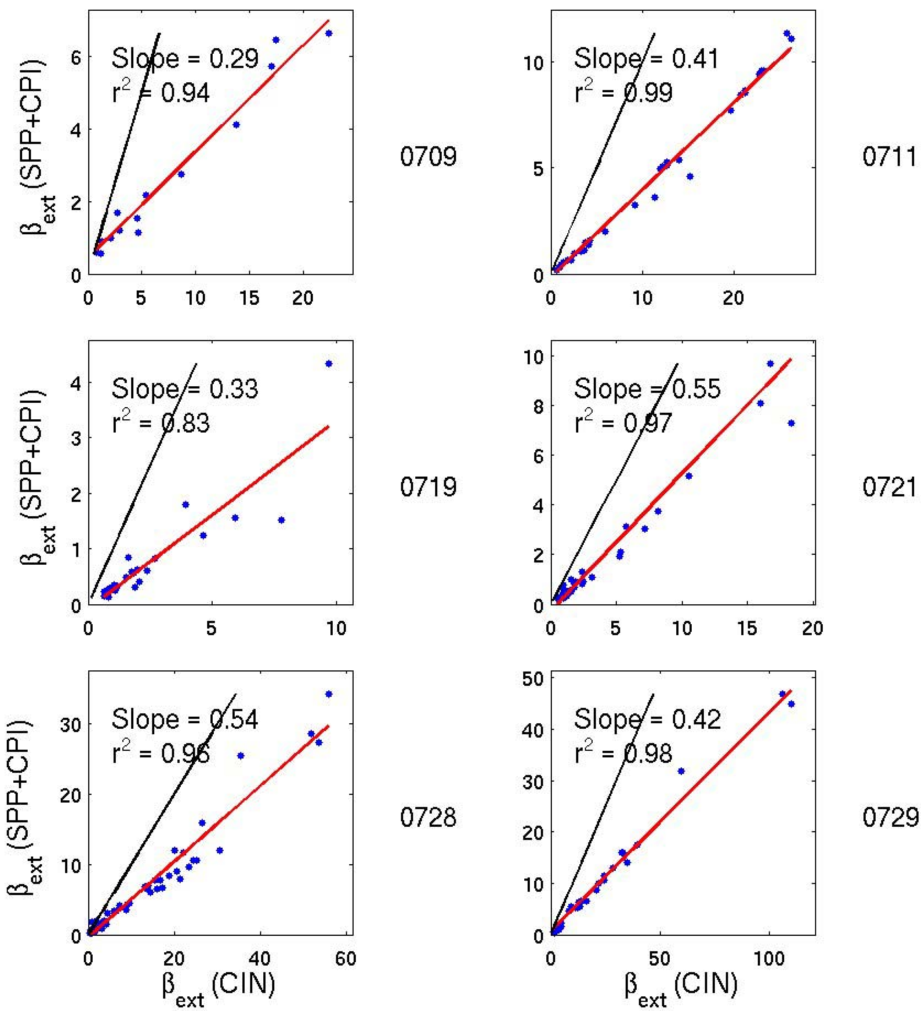
Slope = 0.68
r² = 0.89
0709
Slope = 0.52
r² = 0.99
0711
Slope = 0.94
r² = 0.99
0719
Slope = 0.86
r² = 0.99
0721
Slope = 0.79
r² = 0.99
0728
Slope = 0.82
r² = 0.99
0729
β_ext (CPI<55 μm)
β_ext (CPI)



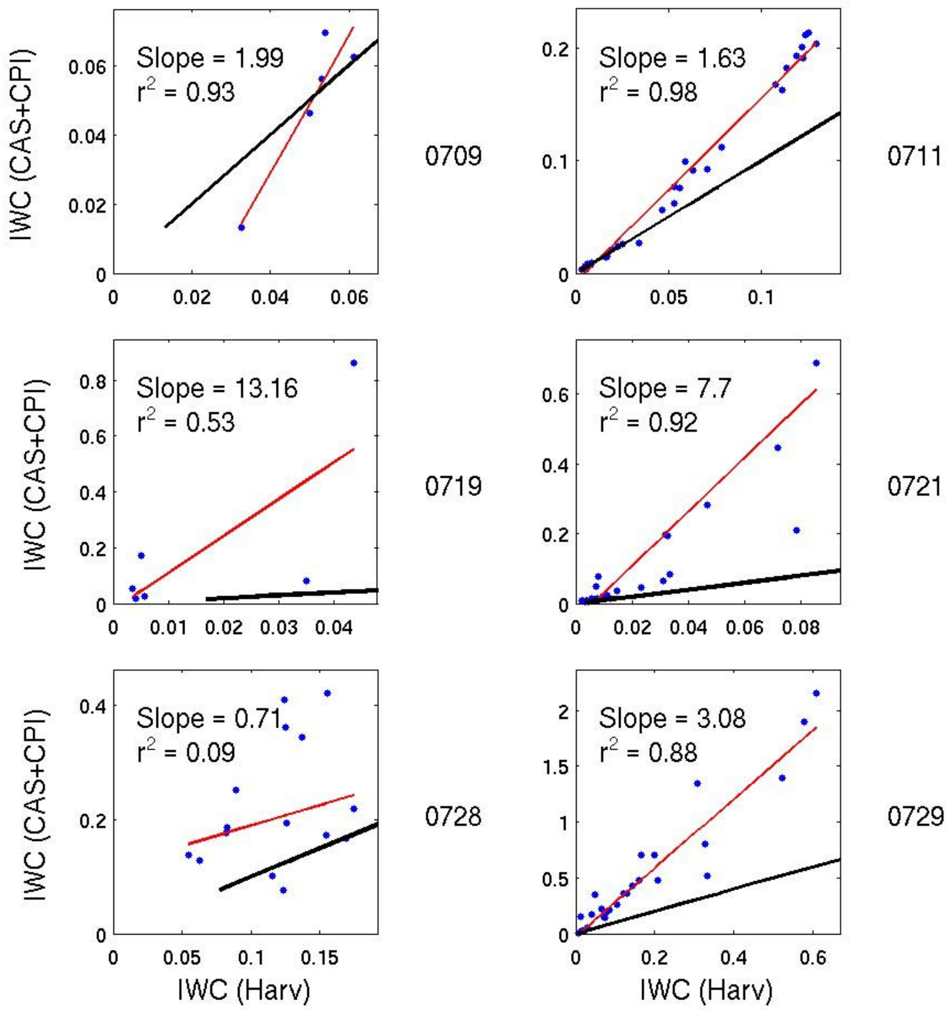
Slope = 0.14
r^2 = 0.4
0709
Slope = 0.24
r^2 = 0.94
0711
Slope = 2.98
r^2 = 0.43
0719
Slope = 2.01
r^2 = 0.84
0721
Slope = 1.2
r^2 = 0.8
0728
Slope = 0.87
r^2 = 0.93
0729
β_{ext} (CPI)
β_{ext} (CIN)



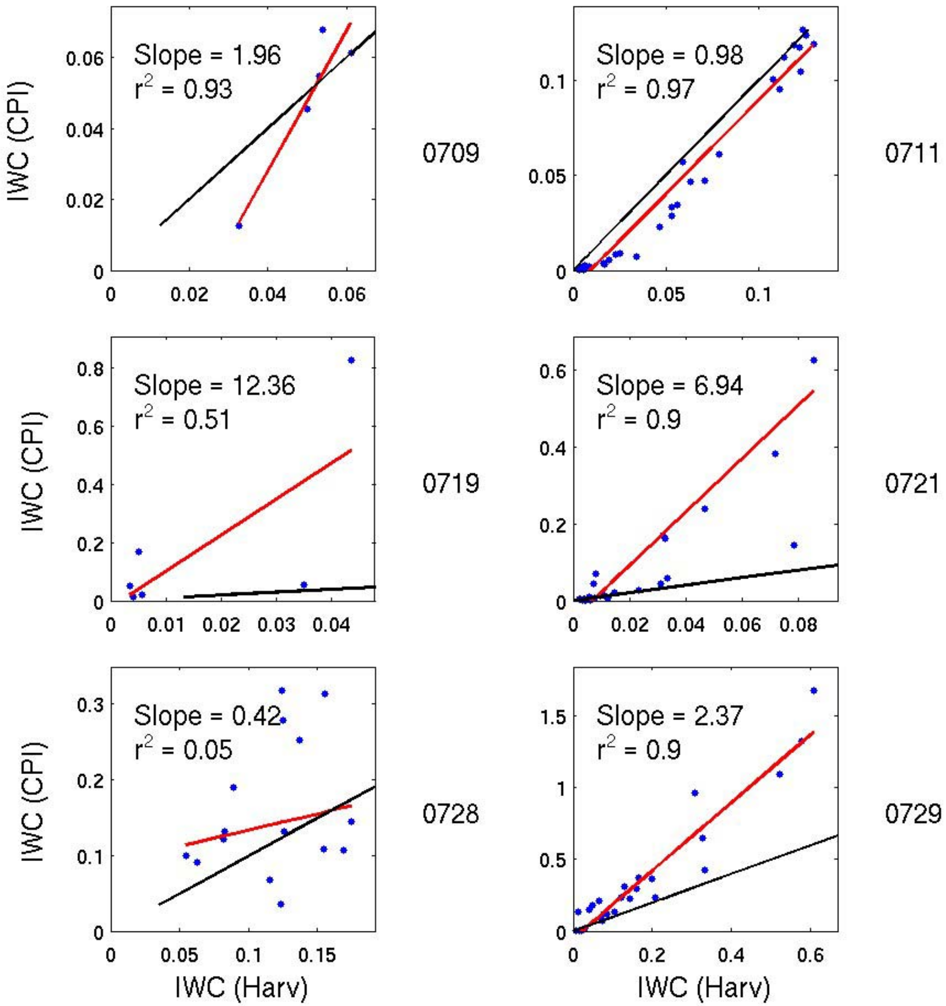
Slope = 0.07
r² = 0.78
0709
Slope = 0.11
r² = 0.96
0711
Slope = 0.23
r² = 0.7
0719
Slope = 0.29
r² = 0.93
0721
Slope = 0.26
r² = 0.86
0728
Slope = 0.15
r² = 0.93
0729
β_ext (CPI>55 μm))
β_ext (CIN)



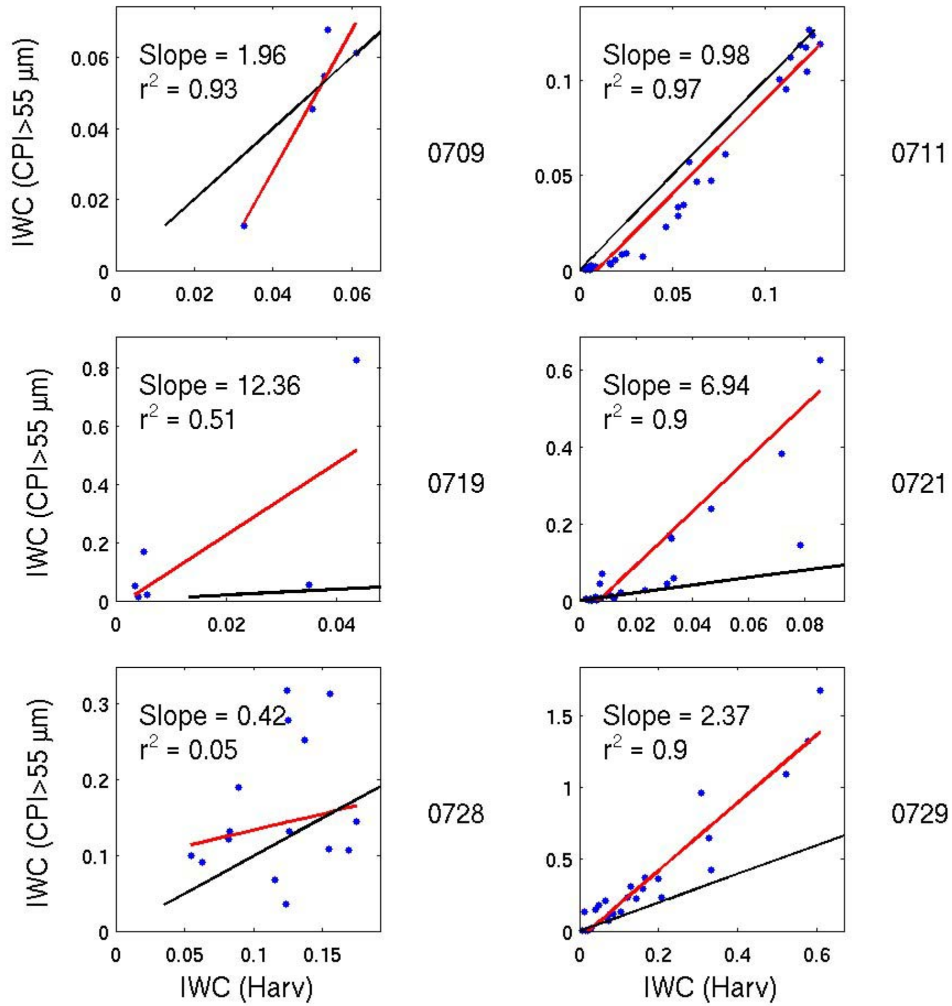
Slope = 0.29
r² = 0.94
0709
Slope = 0.41
r² = 0.99
0711
Slope = 0.33
r² = 0.83
0719
Slope = 0.55
r² = 0.97
0721
Slope = 0.54
r² = 0.96
0728
Slope = 0.42
r² = 0.98
0729
β_ext (SPP+CPI)
β_ext (CIN)



Slope = 1.99
r^2 = 0.93
0709
Slope = 1.63
r^2 = 0.98
0711
Slope = 13.16
r^2 = 0.53
0719
Slope = 7.7
r^2 = 0.92
0721
Slope = 0.71
r^2 = 0.09
0728
Slope = 3.08
r^2 = 0.88
0729
IWC (CAS+CPI)
IWC (Harv)

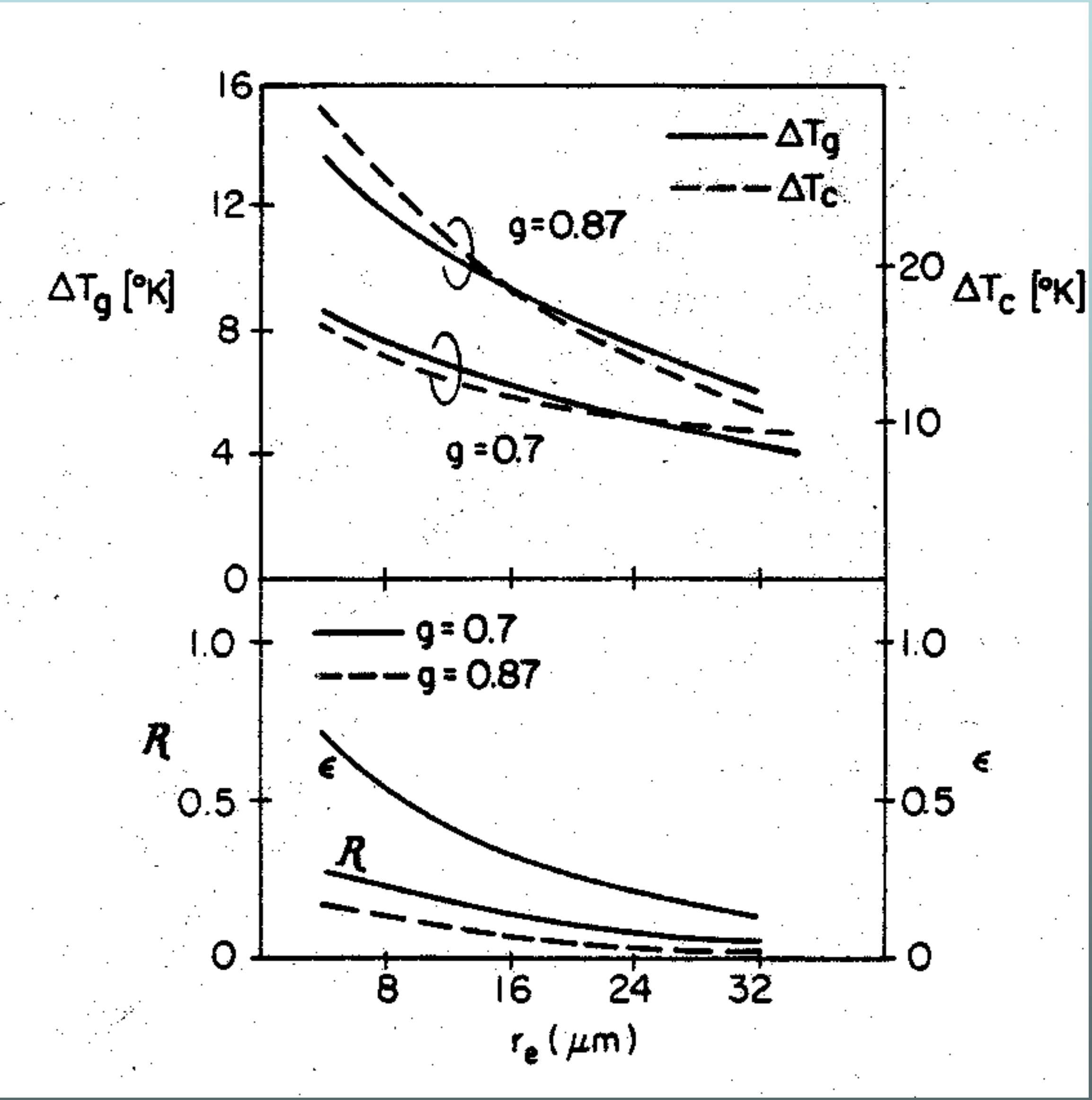


Slope = 1.96
r2 = 0.93
0709
Slope = 0.98
r2 = 0.97
0711
Slope = 12.36
r2 = 0.51
0719
Slope = 6.94
r2 = 0.9
0721
Slope = 0.42
r2 = 0.05
0728
Slope = 2.37
r2 = 0.9
0729
IWC (CPI)
IWC (CPI)
IWC (CPI)
IWC (Harv)
IWC (Harv)



Slope = 1.96
r^2 = 0.93
0709
Slope = 0.98
r^2 = 0.97
0711
Slope = 12.36
r^2 = 0.51
0719
Slope = 6.94
r^2 = 0.9
0721
Slope = 0.42
r^2 = 0.05
0728
Slope = 2.37
r^2 = 0.9
0729
IWC (CPI>55 µm)
IWC (Harv)

Stephens et al., 1990



- Climate is highly sensitive to the assumed value of cloud effective radius over the size range that appears to predominate during CRYSTAL.

- Small values of effective radius generally correspond to high cloud and surface heating.